

# Common Origin of 3.55 keV X-ray line and Gauge Coupling Unification with Left-Right Dark Matter

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We present a minimal left-right dark matter framework that can simultaneously explain the recently observed 3.55 keV X-ray line from several galaxy clusters and gauge coupling unification at high energy scale. Adopting a minimal dark matter strategy, we consider both left and right handed triplet fermionic dark matter candidates which are accidentally stable due to their high  $SU(2)$  dimension forbidding their decay into standard model particles. A scalar bitriplet field is incorporated whose first role is to induce a tiny mass splitting between the left and right handed triplet dark matter candidates by the tiny vacuum expectation value of its neutral component such that the heavier dark matter can decay into the lighter one and a photon with energy 3.55 keV. The other role this bitriplet field at TeV scale plays is to assist in achieving gauge coupling unification at a high energy within a non-supersymmetric  $SO(10)$  model while keeping the left-right gauge symmetry around the TeV corner. Apart from solving the neutrino mass problem and giving verifiable new contributions to neutrinoless double beta decay and charged lepton flavor violation, the model with TeV scale gauge bosons can also give rise to interesting collider signatures like diboson excess, dilepton plus two jets excess reported recently in the large hadron collider data.

## I. INTRODUCTION

Since the observations of galaxy rotation curves made by Fritz Zwicky [1], the evidence suggesting the presence of dark matter in the Universe has been ever increasing with the latest cosmology experiment Planck suggesting around 26% of the present Universe's energy density being made of dark matter [2]. In terms of density parameter  $\Omega$ , the dark matter abundance in the present Universe is reported as

$$\Omega_{\text{DM}} h^2 = 0.1187 \pm 0.0017 \quad (1)$$

where  $h = (\text{Hubble Parameter})/100$  is a parameter of order unity. In spite of growing astrophysics and cosmological evidence in support of dark matter, its particle nature is yet unknown. The characteristics a particle dark matter candidate should satisfy [3] rule out all the particles in the standard model (SM) of particle physics as dark matter candidates.

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With the dark matter direct detection experiments [4, 5] giving null results as of now, there have been growing efforts in the indirect detection frontiers as well. Recently, one promising indirect signature of dark matter was reported by two independent analysis [6] and [7] of the data collected by the XMM-Newton X-ray telescope. Their analysis hinted towards the existence of a monochromatic X-ray line with energy 3.55 keV in the spectrum of 73 galaxy clusters. The analysis [6] also claimed the presence of the same line in the Chandra observations of the Perseus cluster. Later on, the same line was also found in Milky Way by analysing the XMM-Newton data [8]. If there is no astrophysical source behind the origin of this line, then it is very tempting to study a possible dark matter origin of this line. As pointed out by the two teams analysing the above-mentioned data, such a monochromatic line can be naturally incorporated within the framework of sterile neutrino dark matter where a 7.1 keV sterile neutrino decays into a photon and a SM neutrino. Different particle physics models with keV scale sterile neutrino dark matter as possible explanation of the 3.55 keV X-ray line was studied in [9]. A few other theoretical models were also suggested in [10, 11]. Although it is more natural to connect the keV X-ray line with dark matter having similar mass, it is nevertheless worth exploring other possible scenarios. For example, the origin of this 3.55 keV line from electroweak scale dark matter candidates also found some attention in the works [12, 13]. Typically the keV sterile neutrino gives rise to a scenario called warm dark matter (WDM) whereas electroweak scale dark matter is a popular cold dark matter (CDM) candidate and they, in general have very different consequences in astrophysical structure formations. Although there involves fine-tuning in various couplings in a model connecting CDM and keV line, it also has some advantage compared to WDM scenario. For example, according the analysis [6, 7], a keV scale sterile neutrino should have mixing with the SM neutrinos of the order  $\approx 10^{-11} - 10^{-10}$  to explain the observed X-ray line. Since the sterile neutrinos interact with the known SM particles only through this mixing, such a tiny value of mixing angle never allows the sterile neutrino dark matter to enter thermal equilibrium in the early Universe. The puzzle related to the production of sterile neutrino dark matter in the Universe therefore, invites additional new physics. However, CDM is well understood due to their standard weak interaction cross sections falling under the regime of weakly interacting massive particle (WIMP), the most widely studied dark matter framework in the literature.

Although there have been a huge number of WIMP or CDM models in the particle physics literature, it is more interesting to study those models which not only predicts a stable CDM candidate but also provides answers to other open questions in particle physics. Left-right symmetric model (LRSM) [14, 15] is one such highly motivated framework studied extensively in the last few decades from several beyond standard model (BSM) motivations. The model not only explains the origin of parity violation in weak interactions but also explains the origin of tiny neutrino masses naturally. The symmetry group of the LRSM can also be embedded within grand unified theory (GUT) symmetry groups like  $SO(10)$  providing a non-supersymmetric framework to achieve gauge coupling unification. Recently, this model received lots of attention in view of the hints of large hadron collider (LHC) about the existence of new physics around the TeV corner: CMS  $eejj$  excess [16], ATLAS diboson excess [17] and very recently, the 750 GeV diphoton excess [18–20]. From dark matter phenomenology point of view also this model was recently studied [21, 22] in a spirit of minimal dark matter framework [23–25]. In this framework, new particles with high  $SU(2)$  dimensions included in the minimal LRSM are accidentally stable due to the absence of renormalizable couplings that can allow their decay into SM particles. In this work, we

explore this possibility further with a goal of explaining the 3.55 keV X-ray line from dark matter in LRSM. Although it is possible to have sterile neutrino dark matter in LRSM, here we pursue the scenario of CDM origin of the 3.55 keV line [12, 13] by considering a two component left-right dark matter model with a keV mass splitting between the dark matter candidates. To be more specific, we incorporate both left and right handed fermionic triplet into minimal LRSM such that the neutral components of them can be stable CDM candidates. Although the left-right symmetry predicts their masses to be degenerate, we generate a tiny mass splitting naturally by the vacuum expectation value (vev) of the neutral component of a scalar bitriplet field. Interestingly, the same bitriplet with mass around the TeV corner assists in achieving gauge coupling unification at a high scale by keeping the scale of left-right symmetry within the reach of LHC.

This letter is organized as follows. In section II, we briefly discuss the model. In section III we outline the relic abundance calculation of dark matter candidates followed by the discussion on the possibility of generating the 3.55 keV line in section IV. In section V we show the possibility of gauge coupling unification in the model and finally conclude in section VI.

## II. THE MODEL FRAMEWORK

Left-right symmetric model is one of the most widely studied BSM frameworks in last few decades due to the natural origin of tiny neutrino mass and spontaneous parity violation. The symmetry group of the standard model is extended by an additional  $SU(2)_R$  group under which the right handed fermions transform as doublets similar to the way left handed fermions transform under  $SU(2)_L$ . The  $U(1)_Y$  of SM is replaced with an anomaly free  $U(1)_{B-L}$  providing a better understanding of electromagnetic charges of fundamental particles after electroweak symmetry breaking. The model also has an in built discrete symmetry  $Z_2$  which interchanges left and right handed fields thereby making the couplings in both sectors equal (related) or left-right symmetric. Under the symmetry group  $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_c$  of LRSM, the usual quarks and leptons transform as

$$\ell_L \sim (\mathbf{2}, \mathbf{1}, -1), \quad q_L \sim (\mathbf{2}, \mathbf{1}, 1/3), \quad (2)$$

$$\ell_R \sim (\mathbf{1}, \mathbf{2}, -1), \quad q_R \sim (\mathbf{1}, \mathbf{2}, 1/3). \quad (3)$$

while the symmetry breaking is implemented with following scalars

$$H \sim (\mathbf{2}, \bar{\mathbf{2}}, 0), \quad \Delta_L \sim (\mathbf{3}, \mathbf{1}, -2), \quad \Delta_R \sim (\mathbf{1}, \mathbf{3}, -2). \quad (4)$$

The symmetry breaking is achieved as

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \xrightarrow{\langle \Delta_R \rangle} SU(2)_L \times U(1)_Y \xrightarrow{\langle \Phi \rangle} U(1)_Q$$

After the spontaneous symmetry breaking  $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_c \rightarrow \text{SM} \rightarrow U(1)_Q \times SU(3)_c$ , the electromagnetic charge of the components of above fields arise as

$$Q = T_{3L} + T_{3R} + \frac{B-L}{2} \quad (5)$$

The scalar triplets not only play the role of breaking the initial gauge symmetry into that of the SM spontaneously but also generate Majorana masses of heavy and light neutrinos. The scalar bidoublet is needed for spontaneous breaking of SM gauge symmetry to low energy theory of  $U(1)_Q \times SU(3)_c$  so as to give correct masses to electroweak vector bosons and SM charged fermions.

### III. DARK MATTER IN LRSM

Following the minimal left-right dark matter formalism [21, 22], we include two additional fermion triplets  $\Sigma_L \sim (\mathbf{3}, \mathbf{1}, 0)$ ,  $\Sigma_R \sim (\mathbf{1}, \mathbf{3}, 0)$  into the particle content of LRSM. They can be written in component notation as

$$\Sigma_{L,R} = \begin{pmatrix} \Sigma_{L,R}^0 & \sqrt{2}\Sigma_{L,R}^+ \\ \sqrt{2}\Sigma_{L,R}^- & -\Sigma_{L,R}^0 \end{pmatrix}, \quad (6)$$

Due to the absence of any interaction terms mediating the decay of  $\Sigma_{L,R}$  into the SM particles, the lightest component of each of these triplets are accidentally stable and hence can be CDM candidates if they are electromagnetically neutral. Usually, the relic density of CDM is calculated as [26]

$$\Omega_\chi h^2 \approx \frac{3 \times 10^{-27} \text{cm}^3 \text{s}^{-1}}{\langle \sigma v \rangle} \quad (7)$$

where  $\langle \sigma v \rangle$  is the thermally averaged annihilation cross section of dark matter particles multiplied by their relative speed. However, due to small mass difference between charged and neutral components of the fermion triplets, there exists co-annihilation channels which can affect the dark matter relic abundance.

In order to estimate the annihilation and coannihilation channels for triplet fermion dark matter one should know the possible interaction terms given by

$$\mathcal{L}_\phi \supset \sum_{X=L,R} \left[ g_X \sum_{m=1}^n \left( m \bar{\Sigma}_X^m \mathcal{W}_X^3 \Sigma_X^m \right) + \frac{g_X}{\sqrt{2}} \left( \sum_{m=0}^{n-1} c_{n,m} \bar{\Sigma}_X^{m+1} \mathcal{W}_X^+ \Sigma_X^m + \text{h.c.} \right) \right], \quad (8)$$

Since the high  $SU(2)$  dimensions of triplet fermions do not allow them to couple to fermions and scalars, the only interactions affecting relic abundance are the gauge interactions from the above kinetic terms.

Due to the chosen transformation of fermion triplets under the gauge symmetry of LRSM, one can write down their bare mass terms  $M_{L,R} \Sigma_{L,R} \Sigma_{L,R}$  in the Lagrangian where  $M_L = M_R$  by the in built left-right discrete symmetry. As mentioned earlier, our strategy to generate the 3.55 keV X-ray line from left-right dark matter is to induce a mass splitting of 3.55 keV between neutral component of fermion triplets  $\Sigma_{L,R}^0$ . Although this can not be done explicitly due to the in built left-right symmetry, one can achieve it spontaneously after the gauge symmetry breaking inducing a non-zero vev to the neutral component of a bitriplet scalar field. To generate such a tiny mass difference between two dark matter candidates, we introduce a scalar bitriplet field  $\psi \sim (\mathbf{3}, \mathbf{3}, 0)$

$$\psi = \begin{pmatrix} \zeta^{0*} & \epsilon^+ & \zeta^{++} \\ -\zeta^{+*} & \epsilon^0 & \zeta^+ \\ \zeta^{++*} & -\epsilon^{+*} & \zeta^0 \end{pmatrix} \quad (9)$$

the neutral component of which acquires a tiny vev in order to generate the mass splitting. As we know that the electromagnetic coupling between  $\Sigma_L^0$ ,  $\Sigma_R^0$  and  $\gamma$  has to be very much suppressed from the requirement of decaying dark matter to give 3.55 keV X-ray line signal  $\tau(\Sigma_R^0 \rightarrow \Sigma_L^0 \gamma)$ . Assuming the mass splitting between absolutely stable dark matter  $\Sigma_L^0$  and next nearest dark matter  $\Sigma_R^0$  as 3.55 keV, the requirement of giving rise to the 3.55 keV

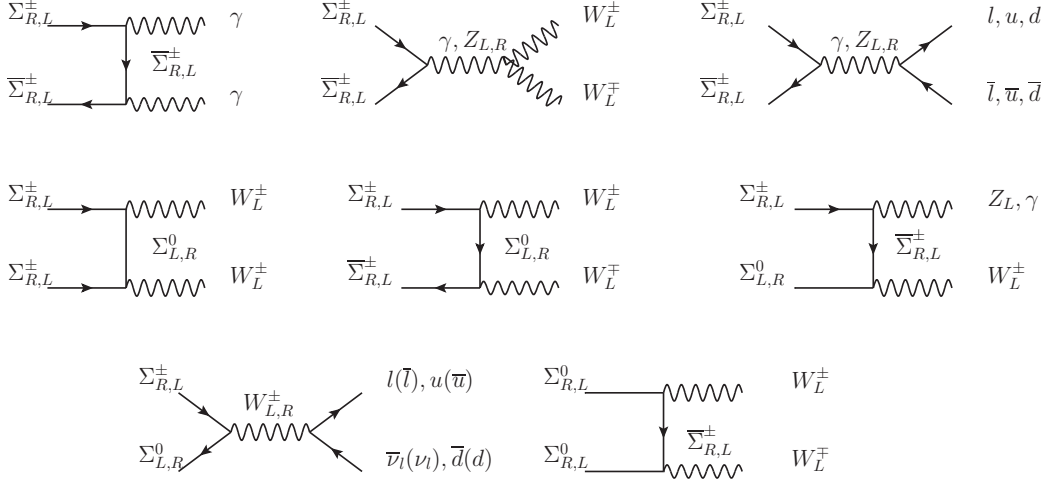


FIG. 1: Feynman diagrams for dark matter (co)annihilations affecting relic abundance.

line puts a constraint  $\Gamma(\Sigma_R^0 \rightarrow \Sigma_L^0 \gamma) = 0.36 - 3.3 \times 10^{-52} (M_{\Sigma_R^0}/3.55 \text{ keV})$ . The suppressed coupling makes it difficult to bring  $\Sigma_L^0$  and  $\Sigma_R^0$  into thermal equilibrium. Additionally, the interactions with scalar bitriplet can also bring affect the coannihilations between left and right components of dark matter. Among bitriplet-triplet interactions, the most important co-annihilation channel is  $\Sigma_1^0 \Sigma_2^0 \rightarrow W_L^+ W_L^-$  through s-channel exchange of neutral triplet  $\epsilon^0$ . The  $\Sigma_1^0 \Sigma_2^0 \epsilon^0$  vertex strength is  $\frac{Y_\psi}{2}$ . On the other hand, the  $W_L^+ W_L^- \epsilon^0$  vertex is proportional to  $g_2^2 \langle \epsilon^0 \rangle$  where  $\langle \epsilon^0 \rangle \sim 3.55 \text{ keV}$ . We however, assume such coannihilation channels to be absent by suitable choice of bitriplet-triplet couplings. Therefore, the relic abundance of both left and right handed triplet dark matter can be calculated independently. However, there exists coannihilation channels between charged and neutral component of a fermion triplet which are taken into account. The (co)annihilation channels included in the calculation of dark matter relic abundance are shown in figure 1.

This effects of coannihilation on dark matter relic abundance were studied by several authors in [27, 28]. Here we follow the analysis of [27] to calculate the effective annihilation cross section in such a case. Using the annihilations and coannihilation processes, the formula for relic abundance for dark matter candidates  $\Sigma_L^0$  and  $\Sigma_R^0$  is given by

$$\Omega_{\text{DM}} h^2 = \frac{1.09 \times 10^9 \text{ GeV}^{-1}}{\sqrt{g_*^{1/2}} M_{\text{Pl}}} \frac{1}{J(x_F)} \quad (10)$$

with the factor  $J(x_F)$  is defined as follows

$$J(x_F) = \int_{x_F}^{\infty} \frac{\langle \sigma | v \rangle_{\text{eff}}}{x^2} \quad (11)$$

where

$$\langle \sigma | v \rangle_{\text{eff}} = \langle \sigma | v \rangle_{\text{eff}}^{\Sigma_L} + \langle \sigma | v \rangle_{\text{eff}}^{\Sigma_R} \quad (12)$$

In the present work with fermion triplet dark matter, the effective annihilation cross-section

for the fermion triplet can be written as

$$\begin{aligned} \langle \sigma | v \rangle_{\text{eff}}^{\Sigma_L} &= \frac{g_{\Sigma_L^0}^2}{g_{\text{eff}}^2} \sigma(\Sigma_L^0 \Sigma_L^0) + 4 \frac{g_{\Sigma_L^0} g_{\Sigma_L^\pm}}{g_{\text{eff}}^2} \sigma(\Sigma_L^0 \Sigma_L^\pm) (1 + \Delta)^{3/2} \text{Exp}(-x\Delta) + \frac{g_{\Sigma_L^\pm}^2}{g_{\text{eff}}^2} (2\sigma(\Sigma_L^\pm \Sigma_L^\pm) \\ &+ 2\sigma(\Sigma_L^+ \Sigma_L^-)) (1 + \Delta)^2 \text{Exp}(-2x\Delta) \end{aligned} \quad (13)$$

where  $\Delta = (M_{\Sigma_L^\pm} - M_{\Sigma_L^0})/M_{\Sigma_L^0}$  is the mass splitting ratio and  $x = M_{\Sigma_L^0}/T$ . Also we denote other parameters like  $g_{\text{eff}}$  as effective relativistic degree of freedom while  $g_{\Sigma_1}$ ,  $g_{\Sigma_2}$ ,  $g_{\Sigma_1^\pm}$  and  $g_{\Sigma_2^\pm}$  are 2 for fermions. The effective relativistic degrees of freedom is related to other spin degrees of freedom is given by

$$g_{\text{eff}} = g_{\Sigma_L^0} + 2g_{\Sigma_L^\pm} (1 + \Delta)^{3/2} \text{Exp}(-x\Delta) \quad (14)$$

Similar expressions can also be written for right handed fermion triplet dark matter. However, as stressed earlier we do not consider any coannihilation between left and right fermion dark matter which allows us to compute the abundance of left and right sector dark matter independently. While calculating the relic abundance, we keep the mass difference between left and right handed fermion triplet to be 3.55 keV as required to explain the monochromatic X-ray line. The resulting relic abundance for  $M_{W_R} = 3, 4$  TeV are shown in figure 2 and 3 respectively. It is seen from both the figures that left-handed triplet dark matter satisfies Planck bound (1) for mass around 2.5 TeV. The right handed dark matter abundance remains suppressed. The dip in the right handed dark matter line around  $m_{\Sigma^0} \approx M_{W_R}/2$  comes from the  $W_R$  resonance. In the case of  $M_{W_R} = 3$  TeV, we do not get right handed dark matter abundance beyond  $m_{\Sigma^0} \approx 2.2$  TeV as the charged component of right handed triplet becomes lighter than the neutral one for that region of parameter space. This is shown as dashed line in the plots shown in figure 2 and 3. Therefore, to realise both left and right dark matter as neutral components of respective fermion triplets while keeping their mass difference 3.55 keV, one needs to consider  $M_{W_R} > 3$  TeV.

#### IV. EXPLANATION FOR 3.55 KEV X-RAY LINE

The monochromatic 3.55 keV line can be explained by the decay of heavier dark matter into the lighter dark matter particle. To introduce this tiny mass splitting, a bitriplet scalar field is introduced whose neutral component can acquire a tiny vev. The relevant interaction Lagrangian is given by

$$M (\Sigma_L^T C \Sigma_L + \Sigma_R^T C \Sigma_R) + \frac{f_\psi}{2} \bar{\Sigma}_L \psi \Sigma_R + \text{h.c.} \quad (15)$$

The mass matrix for neutral fermion triplet in the basis  $(\Sigma_L, \Sigma_R)$  after scalar bitriplet get its usual VEV is given by

$$\begin{pmatrix} M_\Sigma & \delta M_\Sigma \\ \delta M_\Sigma & M_\Sigma \end{pmatrix} \quad (16)$$

where  $\delta M_\Sigma = \frac{Y_\psi}{2} \langle \epsilon^0 \rangle$ . Diagonalizing the above mass matrix we get the following physical masses

$$M_{1,2} = M_\Sigma \pm \frac{Y_\psi}{2} \langle \epsilon^0 \rangle \quad (17)$$

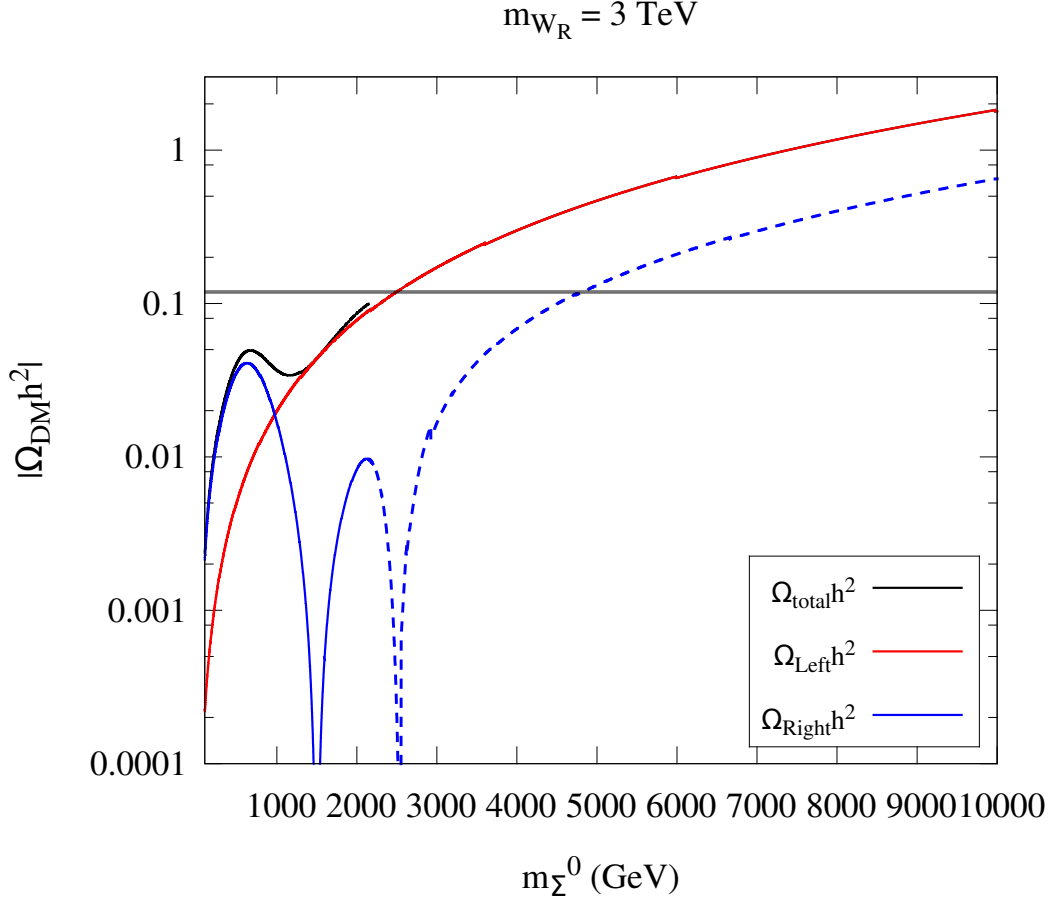


FIG. 2: Relic abundance of dark matter as a function of dark matter mass for  $M_{W_R} = 3$  TeV. The horizontal black line corresponds to the Planck limit on dark matter abundance.

This results a mass splitting between two mass eigenstates as  $\delta = 2\delta M_\Sigma$ . Thus the heavier and lighter dark matter candidates have a mass difference of  $\delta m = Y_\psi \langle \epsilon^0 \rangle$  which is 3.55 keV in our case. Such a tiny mass splitting also kinematically forbids any tree level decay of the heavier dark matter particle into the lighter one and standard model particles. However, at one loop level the heavier dark matter can decay into the lighter one and a photon through the Feynman diagrams shown in figure 4.

The decay of heavier dark matter component into lighter one plus monochromatic photon is possible if the life-time for higher dark matter component is larger than the age of the universe. The same process  $\Sigma_R^0 \rightarrow \Sigma_L^0 \gamma$  is displayed in Fig.4 and the decay width expression

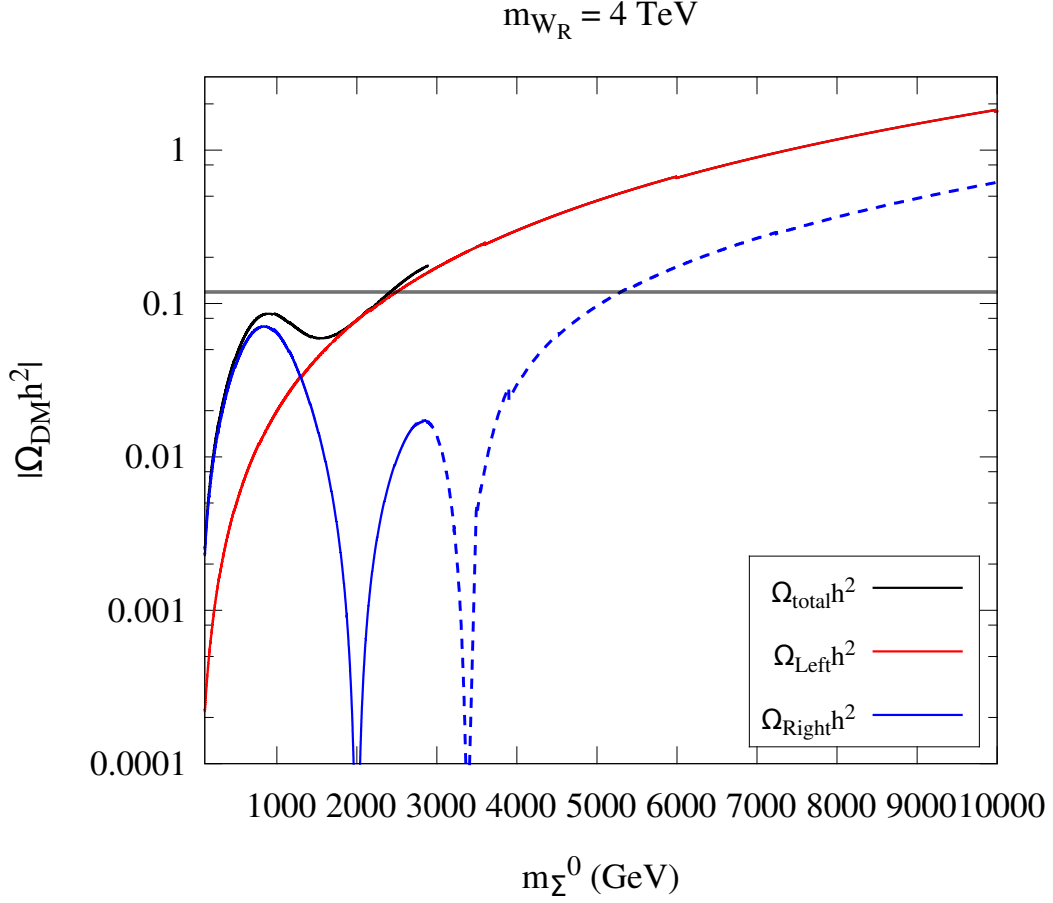


FIG. 3: Relic abundance of dark matter as a function of dark matter mass for  $M_{W_R} = 4$  TeV. The horizontal black line corresponds to the Planck limit on dark matter abundance.

is

$$\Gamma_{\Sigma_R^0 \rightarrow \Sigma_L^0 \gamma} = \frac{e^2}{32\pi} |Y_\psi|^4 \frac{\Delta k^3}{m_{\Sigma_L}^2} |f(m_{\psi^\pm}^2/m_{\Sigma_R^0}^2, m_{\Sigma^\pm}^2/m_{\Sigma_R^0}^2)|^2 \quad (18)$$

$$f(x, y) = \sqrt{x} (B_0(x, y) + 2B_0(y, y) - 3B_0(x, y) + (1 - x + y)G_0(y, x) + 2(3 + x - y)G_0(x, y))$$

$$B_0(x, y) = \int \frac{dl^4}{16\pi^4} \frac{1}{(l^2 - x)((l + p)^2 - y)} \Big|_{p^2=1}$$

$$G_0(x, y) = \int \frac{dl^4}{16\pi^4} \frac{1}{(l^2 - x)((l + p)^2 - y)^2} \Big|_{p^2=1} \quad (19)$$

where

$$\Delta k = m_{\Sigma_R^0} - m_{\Sigma_L^0} = 3.55 \times 10^{-6} (\text{GeV}). \quad (20)$$



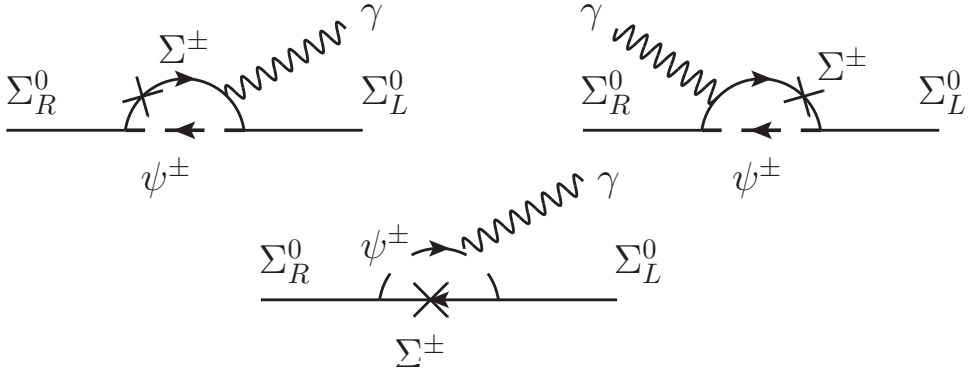


FIG. 4: Feynman diagram for decay of a heavier fermionic triplet component to light one plus photon as an explanation of 3.55 keV X-ray line signal.

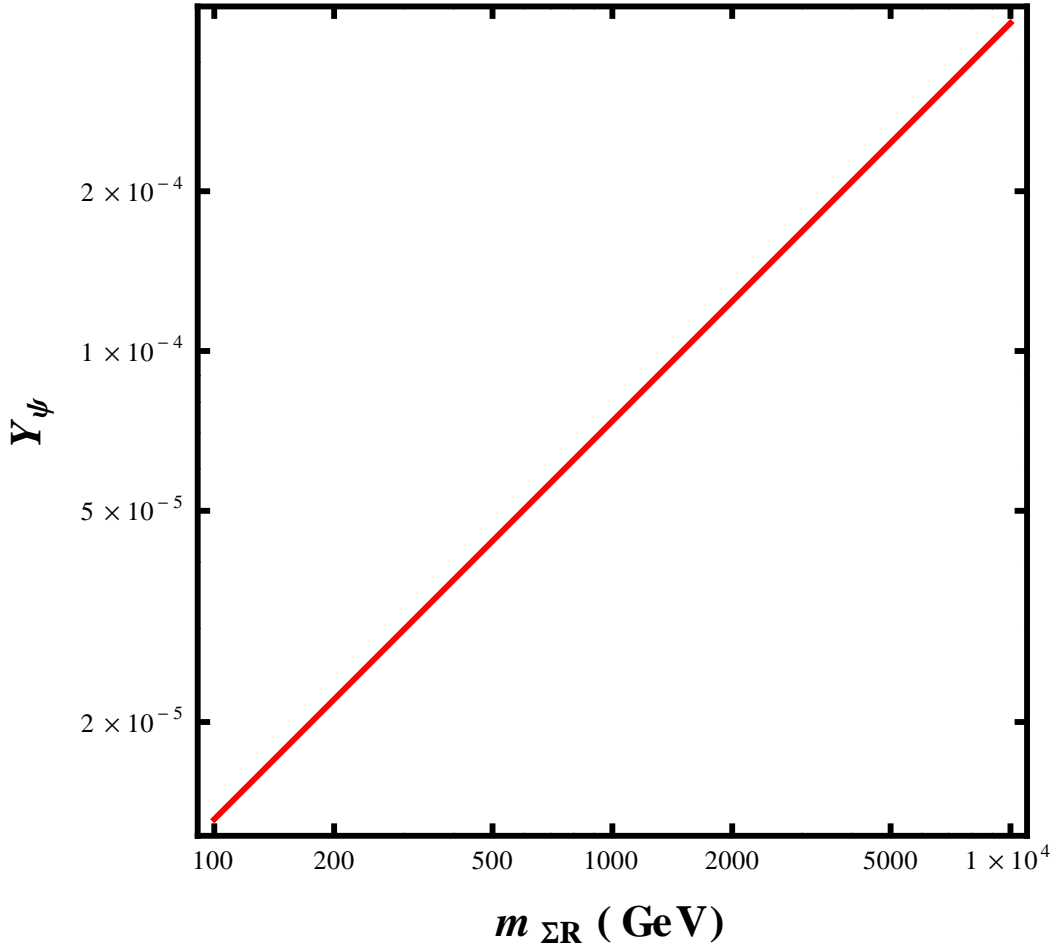


FIG. 5: Constraint on bitriplet-triplet coupling  $Y_\psi$  from X-ray data.

In order to fit our model with the observed 3.55 keV X-Ray line data [6], we follow the

constraint on the decay width of the heavier dark matter candidate  $N_R$  as obtained in [13]

$$\Gamma_{\Sigma_R^0 \rightarrow \Sigma_L^0 \gamma} \approx 6.2 \times 10^{-47} m_{\Sigma_R^0} \text{ GeV}, \quad (21)$$

where  $\Sigma_R^0$  contributes around 50% to dark matter relic abundance. Here the dependence on  $m_{\Sigma_R^0}$  arises via the number density of dark matter. Since the relative contribution to relic abundance need not be 50% in our model, we multiply the right hand side of above equation (21) by a factor  $\frac{1}{2} \frac{\Omega_{\Sigma_R^0}}{\Omega_{\text{DM}}}$ . Considering the mass ratios appearing in the decay width expression to be unity ( $x, y \approx 1$ ), we constrain the dimensionless parameter  $Y_\psi$  and dark matter mass from the requirement of satisfying the above constraints on decay width from X-ray data. The constrained parameter space is shown in figure 5

## V. GAUGE COUPLING UNIFICATION

In the previous sections we have shown that adding fermion triplets and a scalar bitriplet to the minimal left-right symmetric theories can explain the 3.55 keV X-ray line signal seen by XMM-Newton X-ray observatory via the decay of next-to-lightest neutral fermion triplet to the lightest one plus a photon. In this section, our main focus is to examine whether we can successfully embed the framework within a non-SUSY  $SO(10)$  GUT while achieving gauge coupling unification for three fundamental forces along with predicting the ratio  $g_R/g_L$  with TeV scale  $W_R$ .

It is examined that unification of gauge couplings is possible in minimal left-right symmetric model where the left-right gauge symmetry is either broken at very high scale [29, 30] or at TeV scale leading to LHC scale phenomenology [31–33]. Also the gauge coupling unification including left-right symmetric as well as TeV scale stable left-right fermion triplet dark matter added to the conventional LRSM has been studied in recent work [34]. However, we intent here to examine gauge coupling unification by embedding the present framework in a non-SUSY  $SO(10)$  GUT where we have introduced an additional colored scalar and fermion triplet pair as well as a scalar bitriplet for explanation of 3.55 keV X-ray line. Thus, the fermion and scalar content of the model at different symmetry breaking scale is given by

$$\begin{aligned} &\text{From } M_Z - M_R:- \\ &\quad \text{Fermions: } Q_L(2, 1/6, 3), u_R(1, 2/3, 3), d_R(1, -1/3, 3) \\ &\quad \quad \ell_L(2, -1/2, 1), e_R(1, -1, 1) \\ &\quad \text{Scalars: } H(2, 1/2, 1), \\ &\text{From } M_R - M_U:- \\ &\quad \text{Fermions: } Q_L(2, 1, 1/3, 3), Q_R(1, 2, 1/3, 3) \\ &\quad \quad \ell_L(2, 1, -1, 1), \ell_R(1, 2, -1, 1) \\ &\quad \quad \Sigma_L(3, 1, 0, 1) + \Sigma_R(1, 3, 0, 1) \\ &\quad \text{Scalars: } H(2, 2, 0, 1), \eta(3, 3, 0, 1) \\ &\quad \quad \Delta_L(3, 1, -2, 1) + \Delta_R(1, 3, -2, 1) + \xi(1, 3, -1/3, 6) \end{aligned} \quad (22)$$

We found that gauge coupling unification is possible by introducing additional scalar  $\xi(1_L, 3_R, -1/3_{BL}, \bar{6}_C)$  to the above mentioned particle content of the model. Using the

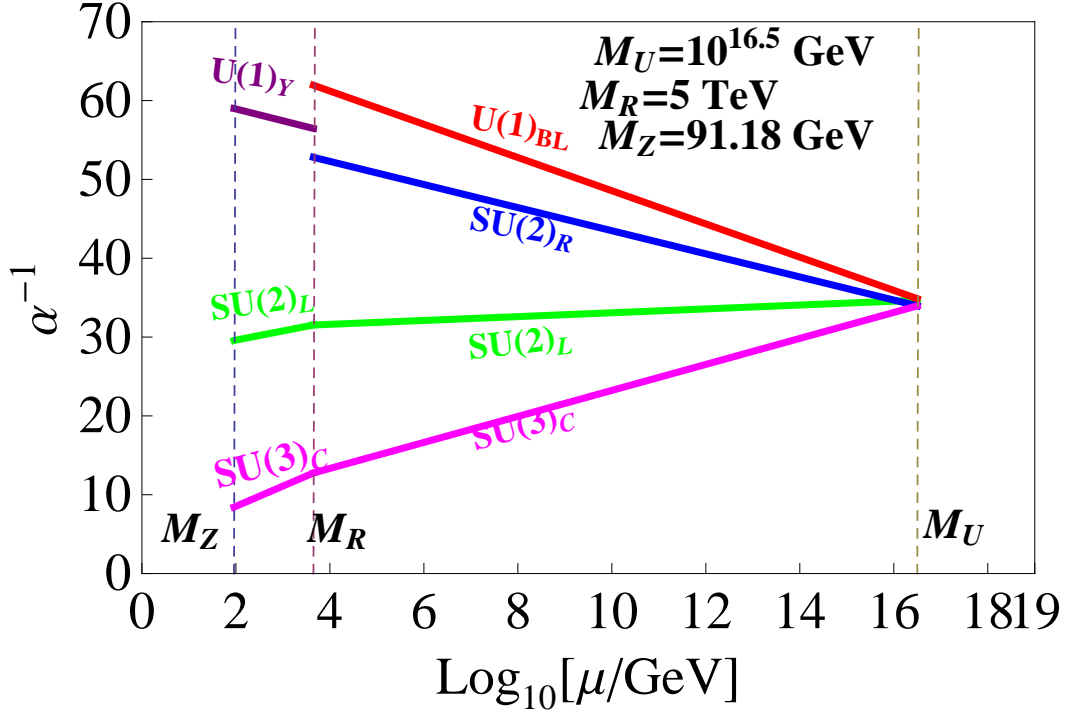


FIG. 6: Unification plot for three gauge couplings accommodating  $W_R$  and fermion triplet around TeV scale where left-right symmetry breaks at 5 TeV and  $M_U \simeq 10^{16.5}$  GeV. We have added an extra scalar multiplet  $\xi(1_L, 3_R, 1/3_{BL}, 6_C)$  from  $M_R$  to  $M_U$  so as to get unification satisfying proton decay constraint.

one-loop renormalization group evolution (RGE) equations for gauge couplings and derived values of beta coefficients,  $b_i = \{-19/6, 41/10, -7\}$  from  $M_Z - M_R$  and  $b_i = \{-2/3, 4, 23/4, -11/2\}$ , the mass scales and  $g_R/g_L$  values are

$$M_U \simeq 10^{16.5} \text{ GeV}, \quad M_R \simeq 5 \text{ TeV}, \quad \frac{g_R}{g_L} \simeq 0.77. \quad (23)$$

Since the left-right symmetry is broken at few TeV scale, we have extra neutral and charged gauge bosons around TeV scale which offers a rich collider studies [35] and in order to explain recent ATLAS and CMS anomalies including diphoton, diboson, dijet searches. The key feature of the model is the low scale  $W_R$  and its discovery potential at LHC. The total cross-section for right-handed charged gauge boson  $W_R$  production within LRSM for  $M_{W_R} \simeq 2 - 3$  TeV and centre of mass energy  $\sqrt{s} = 8$  TeV is related to the mismatch between gauge couplings  $g_R/g_L$  as following

$$\sigma(pp \rightarrow W_R) = 390 \text{ fb} \cdot \left( \frac{g_R}{g_L} \right)^2. \quad (24)$$

## VI. SUMMARY AND CONCLUSION

We have studied a minimal left-right symmetric model with fermion triplet dark matter candidates. The neutral component of these fermion triplets remain accidentally stable due

to their high  $SU(2)$  dimensions that keeps all the interactions leading to their decay into the standard model particles away from the Lagrangian. The neutral components of both the triplets can simultaneously contribute to dark matter relic abundance, resulting in a multi-component dark matter scenario. The discrete left-right symmetry present in the model forces one to have the left and right dark matter masses equal. We introduce a scalar bitriple into the model which introduces a tiny mass difference between left and right dark matter particles. This is possible after the neutral component of the scalar bitriple acquires a tiny vev. Thus, the heavier dark matter can decay into the lighter one while emitting a photon in the process with energy corresponding to the mass difference, which we have chosen to be 3.55 keV in order to explain the observations. We constrain the parameter space by keeping the mass difference between left and right dark matter to be 3.55 keV from the requirement of satisfying Planck data on dark matter relic abundance. We find that the right handed charged gauge boson mass should be larger than 3 TeV in order to satisfy the total relic abundance and to avoid a stable charged fermion from right fermion triplet. We also constrain the model parameters from the requirement of satisfying the constraint on decay width from X-ray data.

We then show how the scalar bitriple which introduce the required mass splitting also assist in achieving gauge coupling unification at high energy scale while keeping the scale of left-right symmetry at TeV scale. We also comment how such a TeV scale LRSM can give rise to other interesting signatures at collider experiments. Such a TeV scale LRSM also has promising signatures at intensity frontier experiments like neutrinoless double beta decay, lepton flavor violation the detailed analysis of which can be found elsewhere.

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